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Technical Report
on

THE OSAKA TUBE AS AN OSCILLATOR IN THE SHORT MILLIMETER WAVES

by

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THE OSAKA TUBE AS AN OSCILLATOR IN THE SHORT MILLIMETER WAVES

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Synopsis

A Barkhausen-Kurz type electron tube with a confining d.c. magnetic field, the so-called Osaka Tube, was designed and fabricated to operate at 2.5 mm wave length with a purpose to study the possibility of its practical fabricability. Oscillation was detected at a wavelength of 2.5 mm at a magnetic field of 4,000 gauss and an anode voltage of 800 volts. No special precision machining was adopted, and therefore the output and efficiency were not the prime purpose of this experiment other than to find the possibility of oscillation. Owing to the restricted cathode area of 0.1 mm^2, it was anticipated that at best an emission current of 1 mA would be drawn. However, actually, an emission current of 4 mA resulted, which indicates that further reduction of operating wave length may be possible. Problems still remain in the mechanical tuning construction and also in the improvement of efficiency, the solution of which lies in the precision of the machining process.

Design Procedure

This work is a continuation of our previous studies[(1)~(3)] on Osaka Tube in the longer millimeter wave region. The present work was aimed at designing an Osaka Tube in the shorter millimeter waves capable of operating at comparatively low anode voltage and magnetic field. These requirements necessitates the reduction of the electrode dimensions. Thus, a choice of 0.5 mm for the distance between the cathode and repeller necessarily results in a distance of 0.1 mm between the repeller and the anode where the spacing becomes closest, since the anode comprising the cavity resonator must be located between the cathode and repeller.

The cavity resonator was machined from a copper disc. (Fig. 1 & 2). Here, it was noticed that the precision of welding to ensure the conductivity of the internal wall of the cavity poses a problem.

The basic relation that governs the electrode dimensions and the operating parameters with regard to the operation frequency is given in Fig. 3 together with the computed results. Here, the computed curve shows the relation between the anode voltage and the magnetic field with respect to the operating frequency. The letter n in the formula and figure denotes the order of the dwarf[(2),(3)] wave. Frequencies of 100 GC, 120 GC and 150 GC represent the central frequencies of the cavity resonators which are to be determined by the designated dimension of the cavity, other dimension as D_x, D_r, etc. being kept constant.

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Experimental Results

Figs. 4, 5 and 6 illustrate the anode current versus anode voltage characteristics under constant magnetic field with the heater input as a parameter.

Fig. 7 shows the current versus voltage characteristics at constant heater input of 1.10 amp. with the magnetic field as a parameter. From these figures it is inferred that the electrons are fairly well formed into bunches that describe to-and-fro oscillations as expected. However, while oscillations readily result with tubes of larger dimensions designed for lower frequencies, the range of oscillation in this extremely short wave region is seen to be small.

An example of the oscillating characteristics is as follows.

V_p = 800 volts	Order of dwarf wave,	n =	15
B = 4000 gauss	Heater power,	P_h =	8 watts
I_p = 200 μ amp.	Wavelength,	λ =	2.6 mm
	Output power,	P_o =	10 μ watts.

The descrepancy of the operating wavelength and the designed value may have resulted from the expansion of the cathode-to-repeller distance during mounting of the electrode parts.

The efficiency and output are expected to be improved if more precise machining is adopted as well as higher voltage and magnetic field are applied for lower n value operation. These aspects remain to be compared with conventional millimeter tubes.

A NEW DESIGN OF OSAKA TUBE IN THE 300 GC RANGE

The conception of Design

The possibility of fabricating an Osaka Tube in the 120 GC band was verified in the foregoing report. Although elaboration of machining process to improve the output and efficiency for the 120 GC tube is necessary, a design of the Osaka Tube in the 300 GC band will be proposed.

An axial symmetrical reentrant type cavity resonator was adopted for the Osaka Tube up to 120 GC, which proved to be a success. However, there seems to be a limitation with this type of cavity in the machining process as well as in the effective coupling between the electron current and the cavity, which seems to be around 150 GC. As a countermeasure, a sort of slow wave structure will be proposed to replace the reentrant type cavity, whereby forced oscillation due to electron current of higher order dwarf waves will be excited, which in turn, through feedback, forms the electron current into more discrete higher order dwarf wave bunching.

The interaction of electron beam and the field of the resonant structure was analyzed and reported (4). According to the analysis, the fundamental component of dipole radiation from an electron beam with square wave configuration of bunching may be expressed as,

$$\overline{dP_o} = \frac{\mu_o}{12\pi c}(q_o dl)^2 \omega_o^4 = \frac{\mu_o}{12\pi c}(Ne\cdot d_g)^2\left(\frac{2}{\pi}\right)^2\left(\frac{2eV_p}{mD_x^2}\right)^2$$

where,
- N = number of electrons that constitute the dipole
- d_g = interaction gap dimension
- V_p = anode voltage
- D_x = cathode-to-repeller distance
- e = electron charge
- m = electron mass

Since the effective dipole moment and the effective angular frequency for the nth order dwarf wave are 1/n and n folds of the fundamental radiation, respectively, the radiation power of the nth order dwarf wave becomes,

$$\overline{dP_n} = \frac{\mu_o}{12\pi c}(Ned_g/n)^2(\frac{2eV_p}{mD_x})^2 n^4 = n^2 dP_o$$

Actually, formation of sharp bunching may be hindered by the space charge effect and therefore the output may not reach the above value.

As a rough estimate, assuming an electron current of 1 mA at an angular frequency of $2\pi\cdot 3\cdot 10^{11}$ rad./sec., we have $N \doteq 3\cdot 10^3$. If $d_g = 0.1$ mm and $\omega = 2\pi\cdot 3\cdot 10^{10}$, we have $\overline{dP_n} \doteq 10^{-10}$ watts. If there are 5 slots along a total length of 1mm, the radiation power is estimated to be about 10^{-8} watts.

Infra-red radiation may be possible with similar construction, though the radiation may not be ideally coherent.

In Fig. 8 are illustrated the construction of the proposed Osaka Tube.

Conclusion

An Osaka Tube was designed and fabricated in the short millimeter region for the purpose to study the practical limitation in fabrication. Preliminary experiments indicated that it was still possible to reduce the wavelength below 2 millimeters. Difficulties of fabrication at this wavelength compares favorably with those encountered with klystrons. However, actual precision machining problems remain to be solved if the absolute output power and efficiency are to be questioned. These will be best solved with the cooperation of manufacturing companies excelling in the field of micro wave electron tubes.

Acknowledgement

This work was partly supported by the ONR Grant and material aid and advices were given by the Oki Electric Industry Co., to whom the authors wish to reveal their gratitude. Thanks are also due to Miss Y. Saito, Messers Y. Yamada and Y. Yamazaki who, as students, had undertaken most of the experimental measurements.

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(1) "The Osaka Tube", by S. Mito & K. Baba, Memoirs of the Faculty of Engineering, Osaka City University, Vol. 1, Dec., 1959.

(2) "Experimental Results with Osaka Tube", by S. Mito & A. Murai, ditto, Vol. 3, Dec., 1961.

(3) "Millimeter Osaka Tube", by S. Mito & A. Murai, ditto, Vol. 4, Dec., 1962.

(4) "Millimeter Osaka Tube", by S. Mito & A. Murai, Report of the Research Committee on Millimeter Waves in Japan, 1960 (in Japanese)

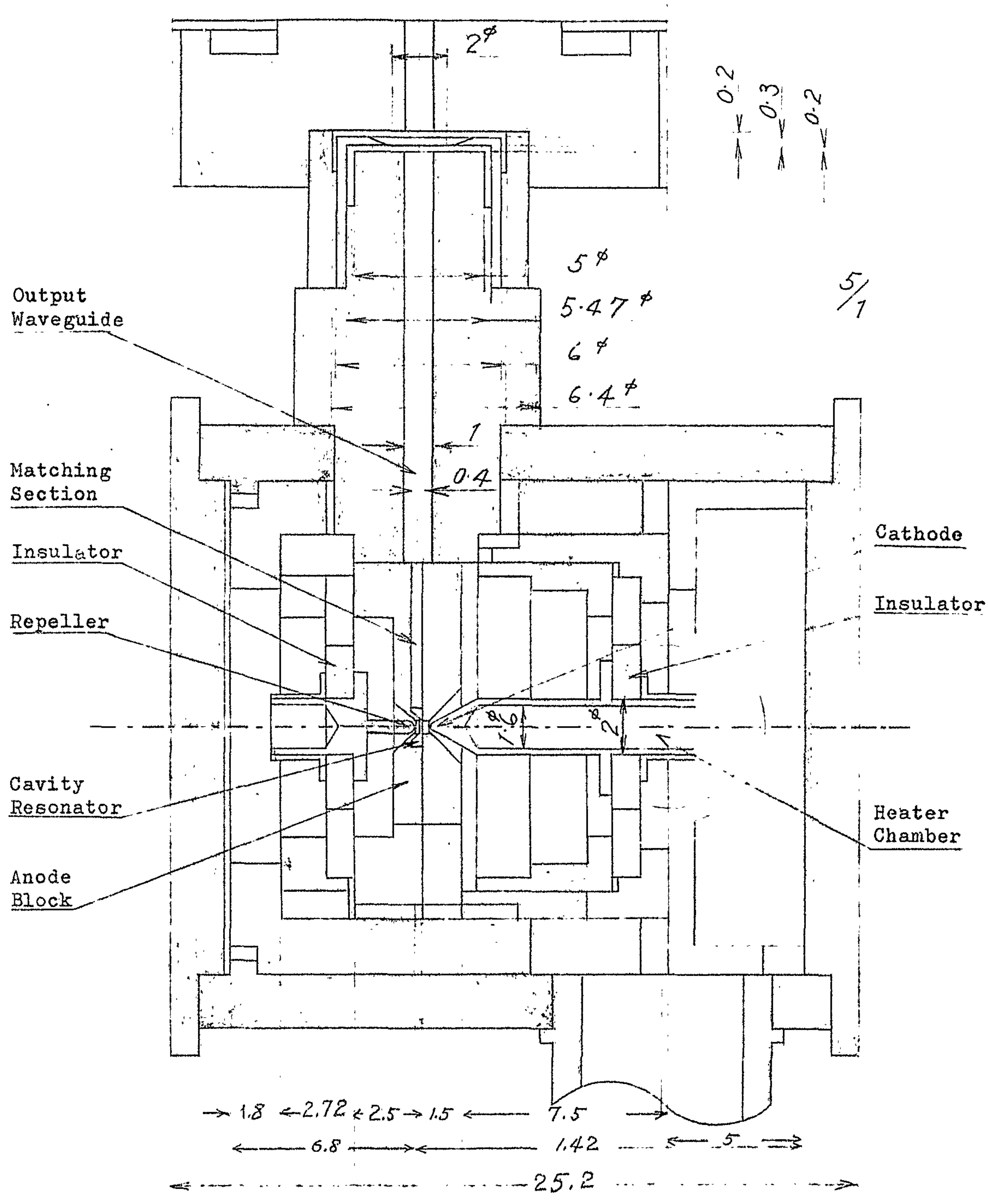
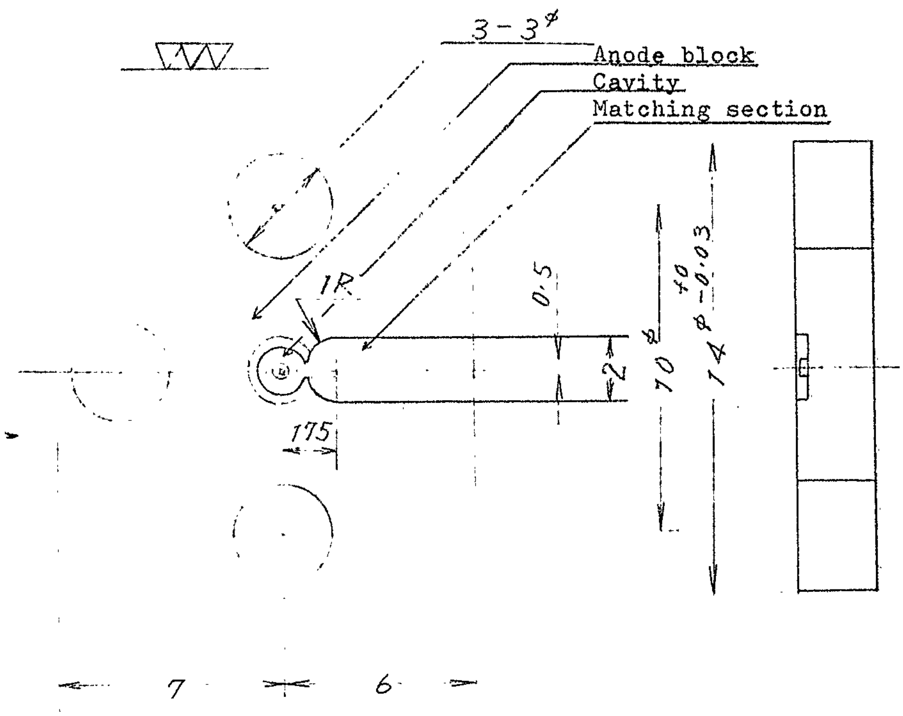


Fig. 1. Construction and dimensions of the 2.5 mm wave Osaka Tube (unit in mm.)



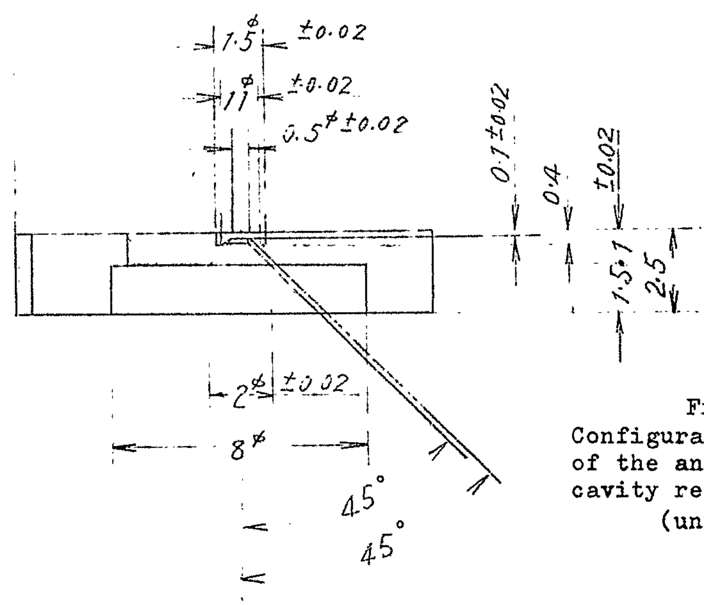


Fig. 2.
Configuration and dimension of the anode block with cavity resonator.
(unit in mm.)

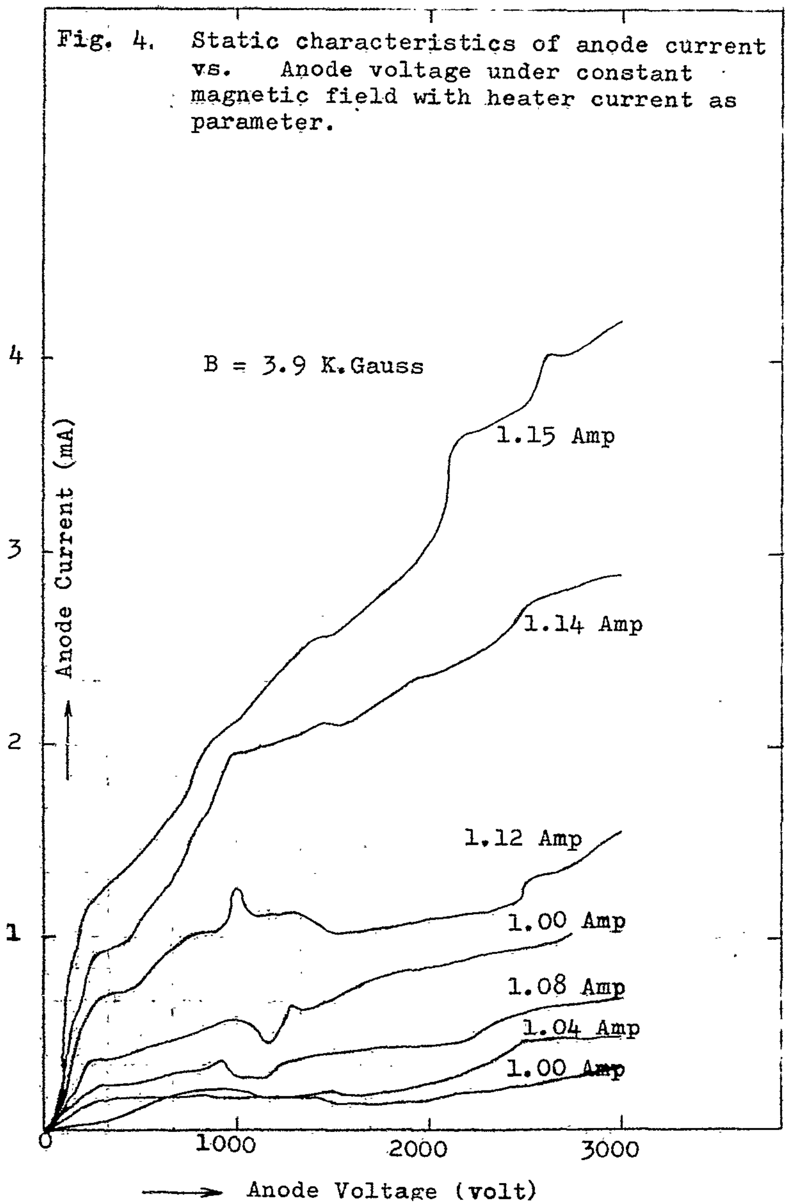


Fig. 4. Static characteristics of anode current vs. Anode voltage under constant magnetic field with heater current as parameter.

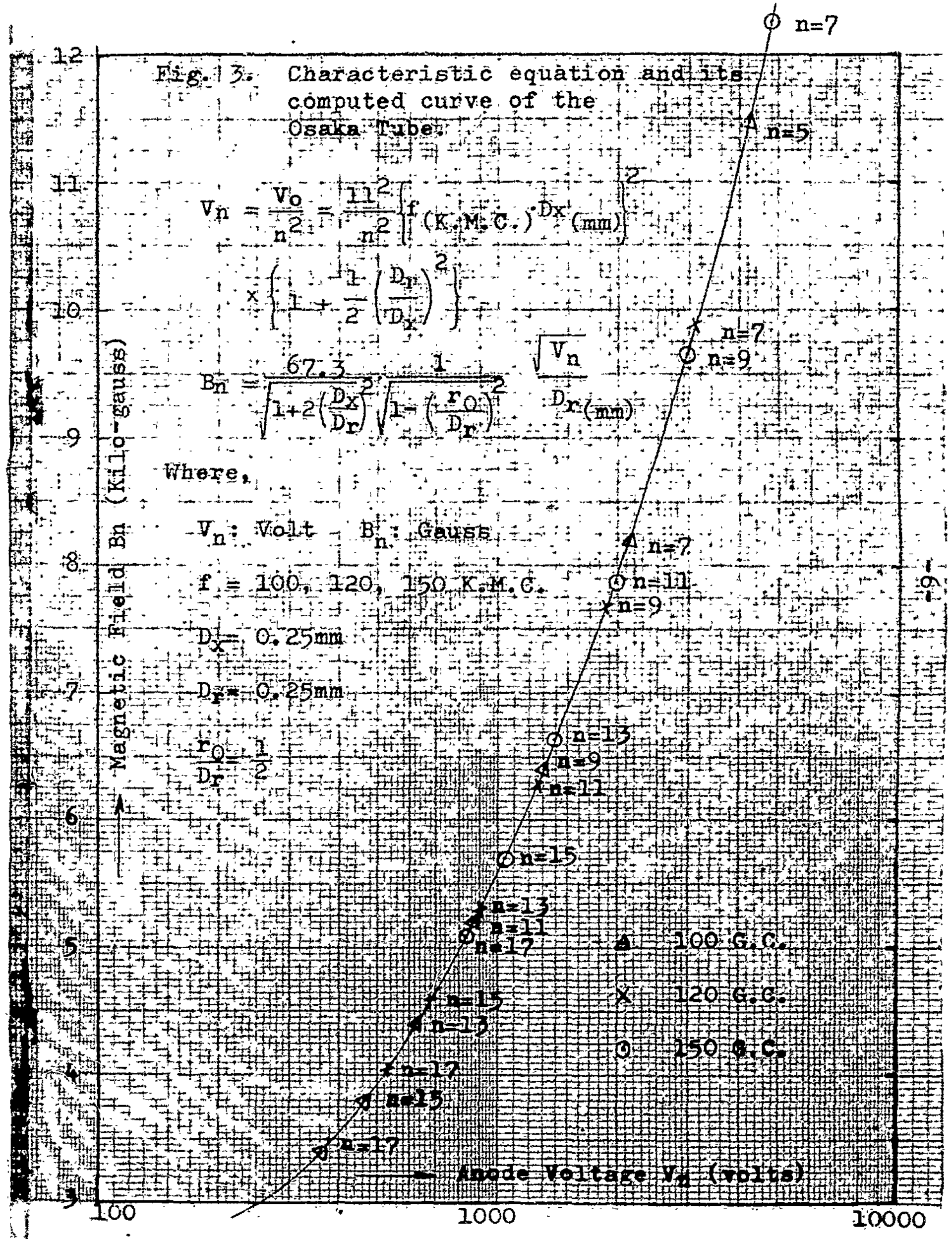


Fig. 3. Characteristic equation and its computed curve of the Osaka Tube.

$$V_n = \frac{V_0}{n^2} = \frac{11^2}{n^2}\left\{f_{(K.M.C.)}\,D_{x\,(mm)}\right\}^2 \times \left\{1 + \frac{1}{2}\left(\frac{D_r}{D_x}\right)^2\right\}$$

$$B_n = \frac{67.3}{\sqrt{1+2\left(\frac{D_x}{D_r}\right)^2}} \frac{1}{\sqrt{1-\left(\frac{r_0}{D_r}\right)^2}} \frac{\sqrt{V_n}}{D_{r\,(mm)}}$$

Where,

V_n : Volt B_n : Gauss

f = 100, 120, 150 K.M.C.

D_x = 0.25mm

D_r = 0.25mm

$\frac{r_0}{D_r} = \frac{1}{2}$

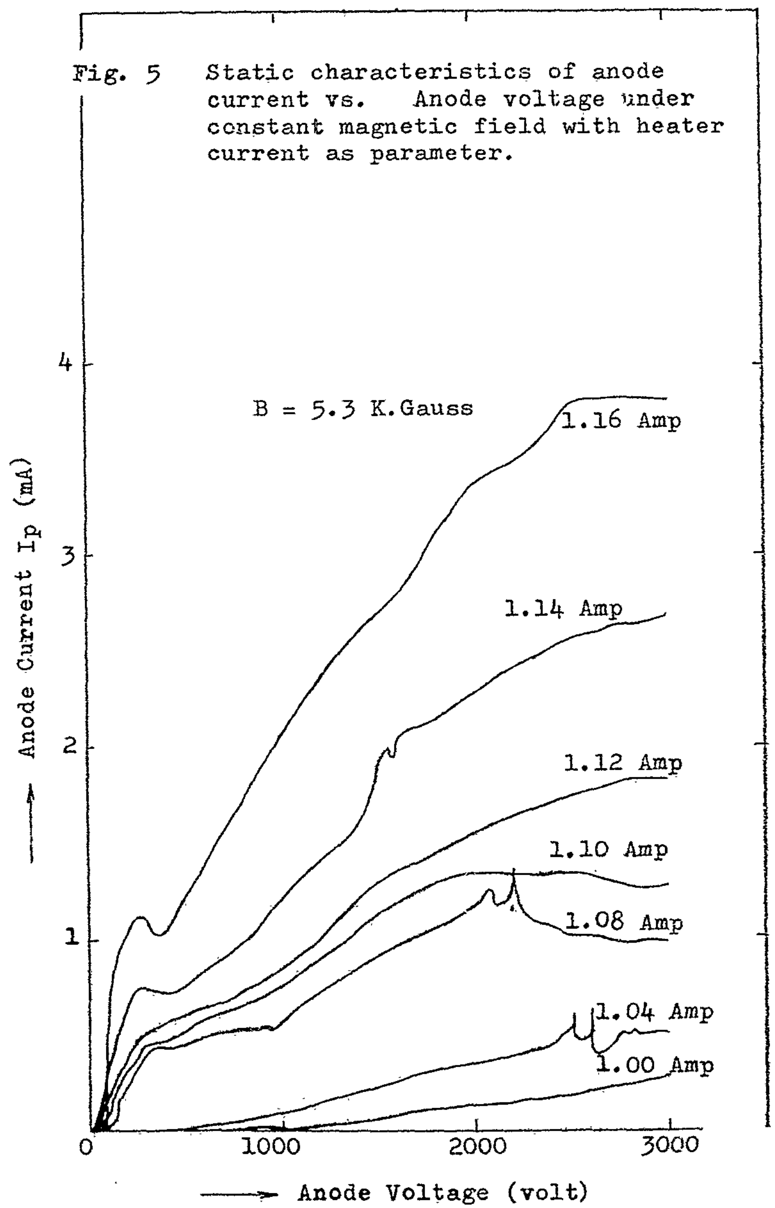


Fig. 5 Static characteristics of anode current vs. Anode voltage under constant magnetic field with heater current as parameter.

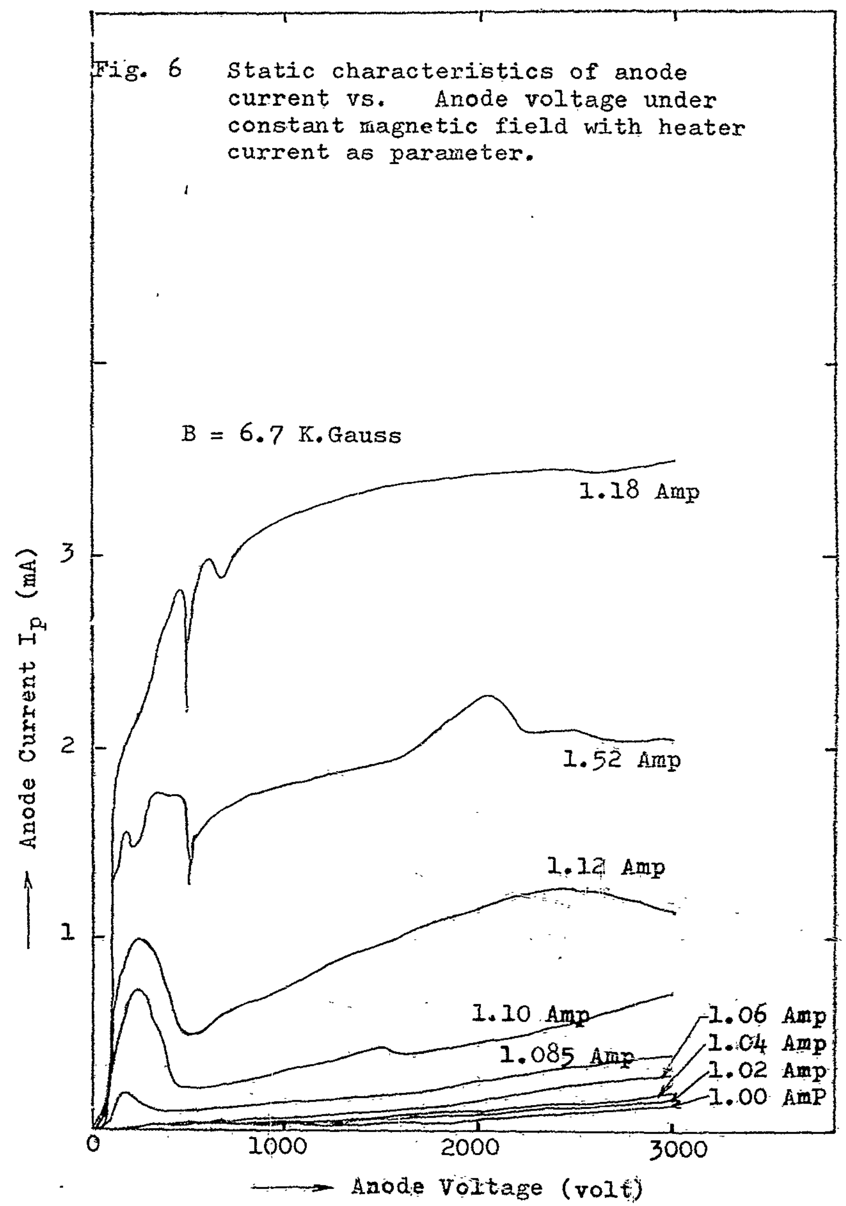


Fig. 6 Static characteristics of anode current vs. Anode voltage under constant magnetic field with heater current as parameter.

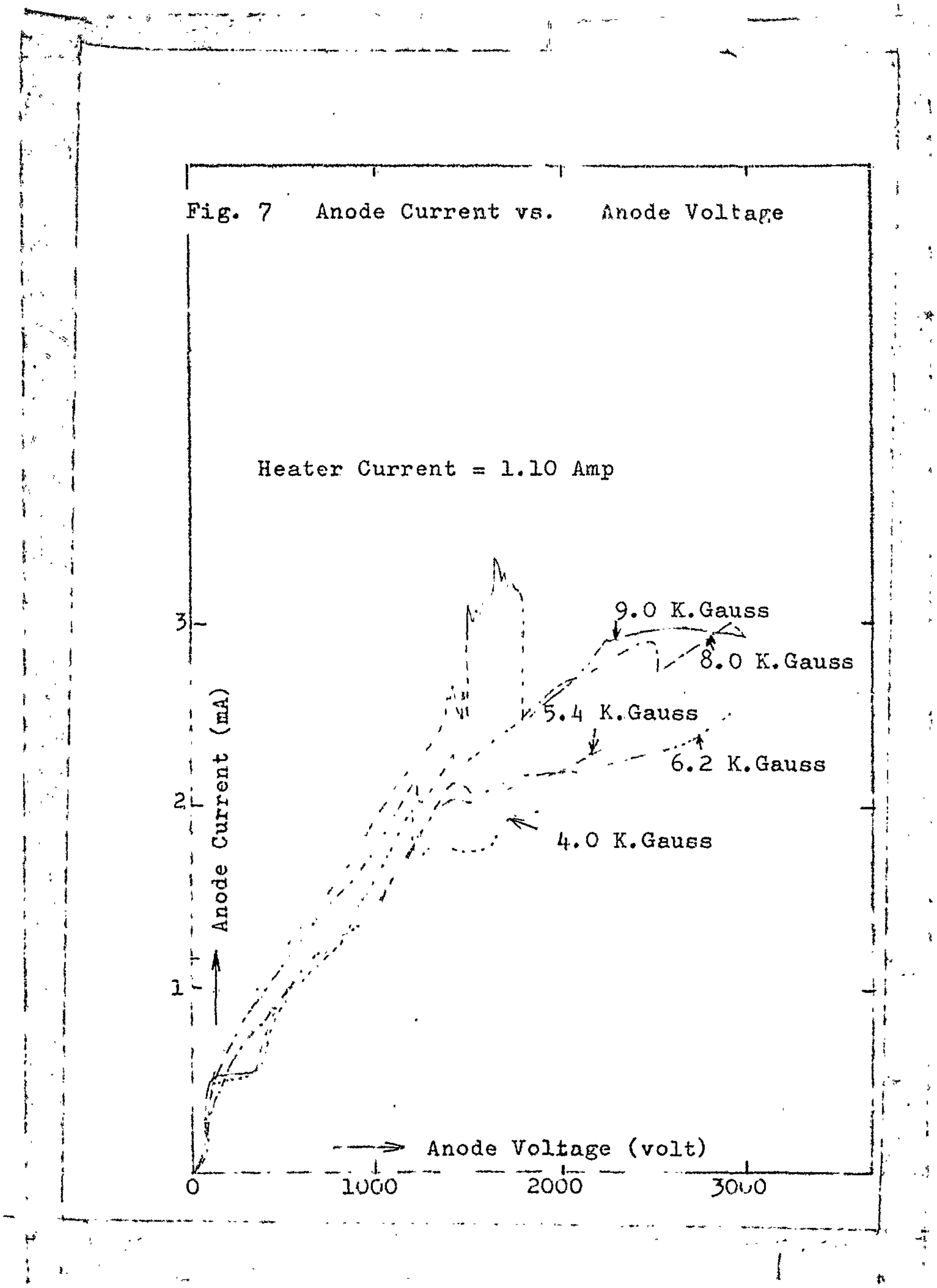
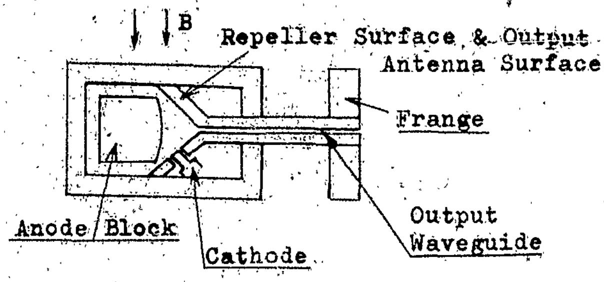
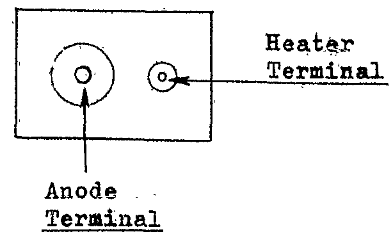


Fig. 7 Anode Current vs. Anode Voltage
Heater Current = 1.10 Amp
9.0 K.Gauss
8.0 K.Gauss
5.4 K.Gauss
6.2 K.Gauss
4.0 K.Gauss
Anode Current (mA)
Anode Voltage (volt)
3
2
1
0
1000
2000
3000

Fig. 8 Electrode Construction of 300 GC Osaka Tube.

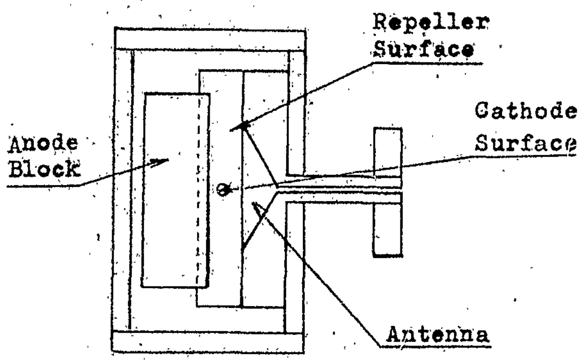


a. Vertical Center Cross Section (x1)

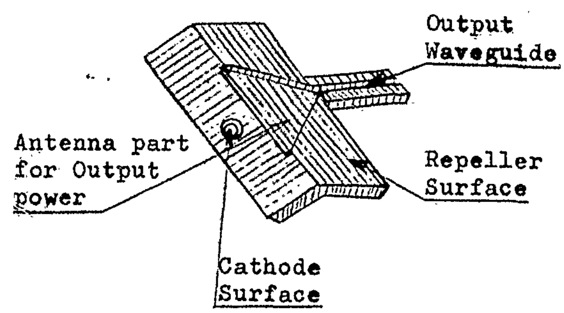


(Positive power supply connect to the Anode, Cathode Surface and one Heater connect to the earth potential.)

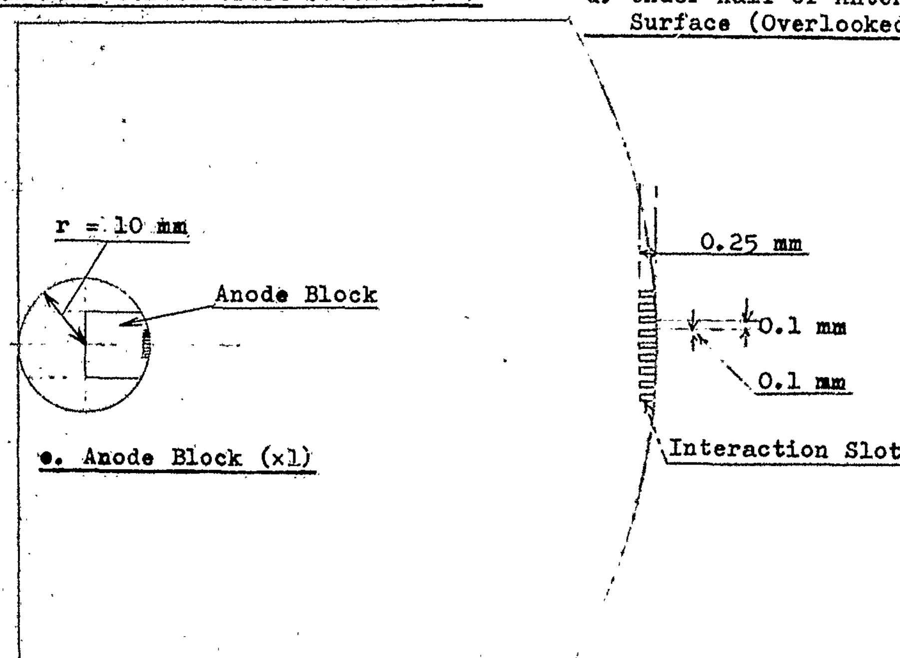
c. Side View (1)



b. Horizontal Center Cross Section (x1)



d. Under half of Antenna Surface (Overlooked)



e. Anode Block (x1)

f. Anode Block (x10)